4.8. COLONIZATION OF ARABLE FIELDS BY EARTHWORMS IN A NEWLY RECLAIMED POLDER IN THE NETHERLANDS —PRELIMINARY RESULTS[1]

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INTRODUCTION

Over the last few decades, intensive agricultural practices in The Netherlands have probably reduced earthworm populations in arable land. Nowadays, reduced input production is the subject of an increasing research effort. One way to minimize inputs is to reduce tillage, using natural processes of soil structure conditioning. To help this process, (re)colonization of earthworms should be considered.

Little is known about the mechanisms involved in the colonization by earthworms. Mostly transport to new areas can be either by the activity of the animals themselves (active dispersal) or through the action of other agents (passive dispersal). Schwert (1980) described two ways of passive dispersal, transport by stream drift (along the borders of rivers), or by other animals. Cattle can be effective in spreading earthworm cocoons with the mud on their hooves (J.P. Curry, pers. comm.). Schwert (1980) described one way of active dispersal only, by mass emergence occurring under stress conditions. However, under normal conditions, active dispersal can also be expected to be a result of the random movement of earthworms through the soil, a behaviour that is necessary for endogeic species to feed themselves. If the random movement of individuals is involved, then the rate of spread of the population border depends on both population growth and the activity pattern of the individuals (Williamson and Brown, 1987).

It is likely that factors involved in determining the rate of spread of earthworm populations (population growth, individual rate of both active and passive dispersal) may be different under varying conditions. In grassland plots population growth can be high, and passive dispersal is restricted to small amounts of soil in cattle hooves. In grasslands in newly reclaimed polder soils colonization proceeded with a rate of approximately 8 metres per year for *A. caliginosa* and *L. rubellus* (Hoogerkamp *et al.*, 1983). Curry and Boyle (1987) studied the establishment of earthworm populations in grassland on reclaimed

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cutover peat. They found a dispersal rate from inoculum sod of at least 2.5 m yr^{-1} for *A. caliginosa*, and 10 m yr^{-1} for *L. rubellus*.

In arable fields, active colonization can be expected to be much slower, because of less favourable conditions for earthworms, resulting in lower population densities. On the other hand, individual movement may be stimulated by lower food availability (Martin, 1982). Passive dispersal by soil transport with tractor wheels may also take place under arable conditions. This type of spread would cause a skewed distribution in the direction of the main tillage operations, and would take place mainly during tillage carried out under relatively wet conditions.

From the foregoing can be concluded that, to be able to predict colonization rates under different conditions, it is necessary to measure parameters of both active and passive dispersal. In this study, measurements of individual dispersion range and an estimation of passive transport rate under arable conditions are presented.

SITE DESCRIPTION

The site where the research was carried out is the ''Lovinkhoeve'' experimental farm in the Noord Oost Polder, which was drained in 1943. The soil is a calcareous sandy loam soil (Brussaard *et al.*, 1988). Different parts of the farm received different treatments (see Fig. 1). Southeast of the farm the fields have been under pasture since 1943, but are now used as arable land. South to Southwest of the farm a plot has been treated with different types of fertilizer. Block-A received farmyard manure, inorganic fertilizer and green manure, block-B received only inorganic fertilizer, while block-C received both green-manure and inorganic fertilizer. Since 1985 the fields of this block have been split into blocks with conventional and integrated crop production. The integrated crop production is characterized by lower inputs of inorganic fertilizer and biocides, increased use of organic manuring and reduced tillage (for details see Brussaard *et al.*, 1988). South of these blocks a long-term tillage experiment has been established, where minimum and conventional tillage methods are compared.

Figure 1 illustrates the distribution of the earthworm population during 1987 (in June and October). Population density and species diversity were the highest in the most northern plot which was a grassland until recently. The minimum tillage plot, farther away from the farm, did not have earthworms. In block B, which received only inorganic fertilizer, earthworms were absent or rare, only in the integrated part of the block-B some *L. rubellus* occurred. In the southernmost field of the block-A one species (*L. rubellus*) was present, while in the field closer to the farm the endogeic species *A. caliginosa* and *A. rosea* were also present.

METHODOLOGY

To estimate active and passive dispersal, two experiments were carried out. For the measurement of active dispersal, earthworms were inoculated in a minimum tillage plot in April 1987. One hundred and twenty individuals, both adults and sub-adults of *A. caliginosa* were laid on the surface of a 1 m^2 quadrant, that were free from tractor tracks. There were four replicates. The plots were covered with a thin layer of compost to prevent the night frost from harming the worms. The compost was removed after one week, but some remained in small cracks in the upper soil. When necessary, the plots were

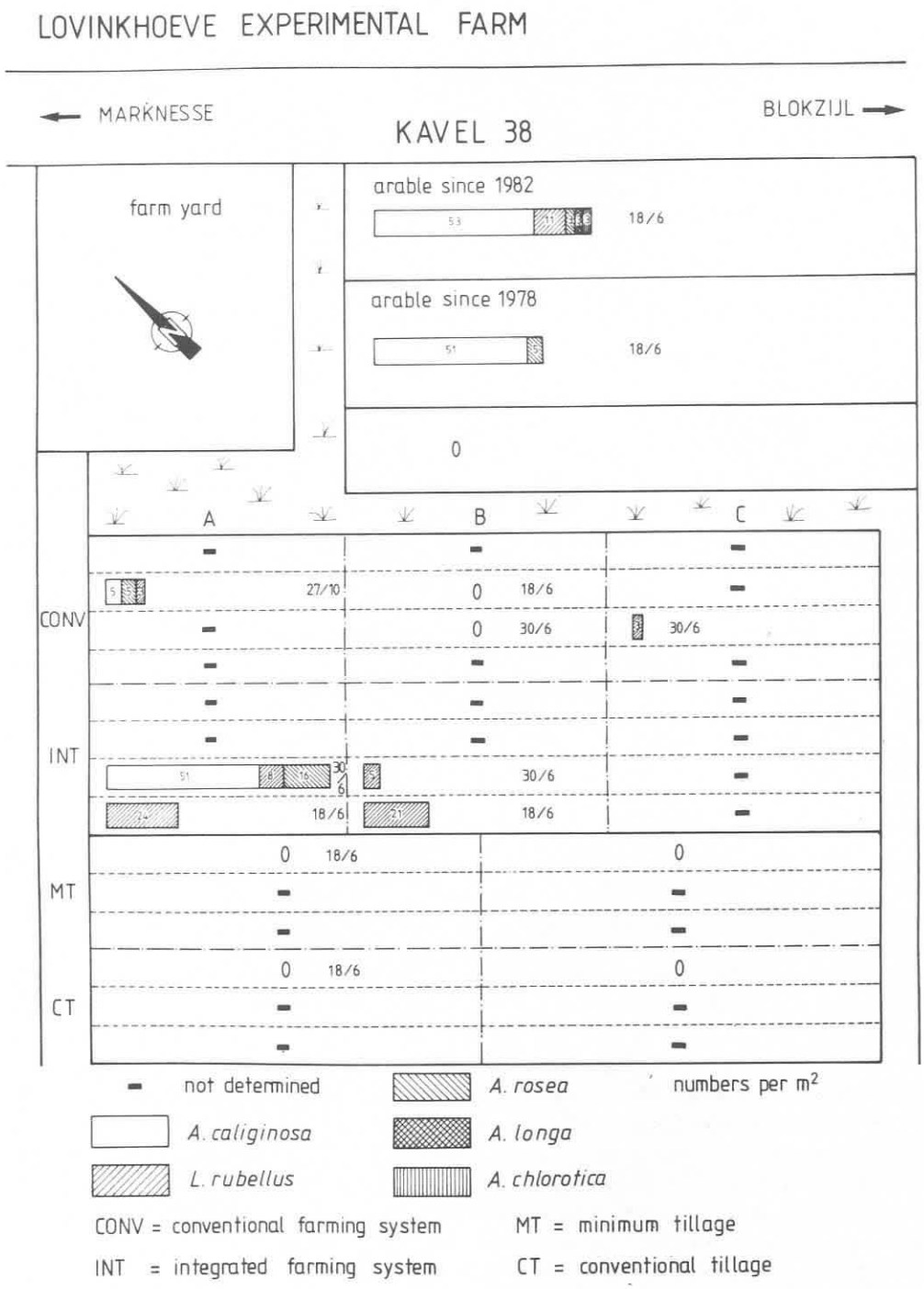

Fig. 1. Map of Lovinkhoeve experimental farm, including earthworm distribution over the farm.

watered to keep the soil moist enough for earthworm activity. This watering was only necessary in June; the summer of 1987 was extremely wet. On October 6, survival and spread was assessed by sampling one $20 \times 20 \times 20$ cm^3 subplot, at an inoculation site and two more, one and two metres away from it. Because of the destructive nature of the sampling, only two inoculation plots and adjacent areas were sampled. The soil was washed away over a sieve, and from the debris earthworms and their cocoons were collected. The period from April to October covers the main part of the active period of the earthworms, cold and frost limiting activity during the rest of the year. Also harvest (mid-October) and subsequent tillage disturbs the active dispersal pattern.

In a second experiment, passive dispersal of cocoons by tractor wheels was simulated using small (2mm) glass beads. In a plot of roughly the size of a tractor wheel imprint over one revolution (30×500 cm), 2900 coloured glass beads were pushed into the soil with thin wooden pins to a depth of 1.5, 3.0 and 4.5 cm, each depth represented by a different colour. These depths were chosen because the ridges on the tractor wheel were 5 cm high, and it was not expected that beads buried deeper would be in reach of the wheel. There were five replicates. After a weekend of heavy rainfall, when the soil was sticky, a tractor was driven with the right wheels over the plot and over 65 m of bare soil with normal ploughing speed. Subsequently, the soil adhering to the right wheels was sampled for the remaining beads. All the soil was removed from the wheels before the tractor was allowed to drive to the next replicate (a distance of about 80 m, enough to fill the wheels with soil again). In the track the right wheels made, all clods that fell from the wheels were sampled at intervals of 5 m from the inoculum point. The clods were weighed and the number of beads in them determined by a washing and sieving procedure. Also in the first 25 m of each track after the inoculum plot, every 5 m a random sample of $20 \times 20 \times 7$ cm was taken, and the number of beads in it measured. In the inoculation plot, three such samples were taken to determine the number of beads that were left over after the passage of the wheels.

RESULTS

The inoculation experiment in the minimum tillage plot showed good survival of the introduced earthworms. The results of the counts are given in Table 1. *L. rubellus* had appeared in the plots, although it was not introduced deliberately. Possibly *L. rubellus* cocoons were introduced with the compost cover, which was not completely removed. From the presence of earthworm casts on the surface, it became clear that the earthworms had not spread over more than 2-3 m from the inoculation plot. From Table 1 it appears that *L. rubellus* has spread over a distance of 2 m, while *A. caliginosa* did only incidentally come much farther than 1 m.

The results of the passive dispersal experiment are presented in Fig. 2 and 3, and Table 2. The distribution of glass beads over the field in the clods (Fig. 2) shows a regular pattern for the first 35 m, then decreases sharply. In the wheel track itself (Fig. 3) the highest amounts of beads were found. Most were recovered in the first 15 m, followed by a sharp decline. The balance of numbers of beads recovered is given in Table 2. Of all the beads, on the average 50.2% was removed from the plot where they were applied. More beads that were buried superficially (yellow) were transported than those buried deeper. After 65 m, only few beads (3.1%) were still adhered to the wheels. In case of the superficially and deepest buried beads, 8.8 and 21.4% respectively of the beads were not recovered.

Table 1. Number of earthworms found in inoculation plots and adjacent areas (total of two replicates)

	Number in sub plots of size 20 × 20 × 20 cm^3 in		
	Inoculation plot	1 m further away from inoculated plot	2 m further away from inoculated plot
A. caliginosa			
worms	29	1	0
cocoons	25	2	1
L. rubellus			
worms	2	0	2
cocoons	16	41	16

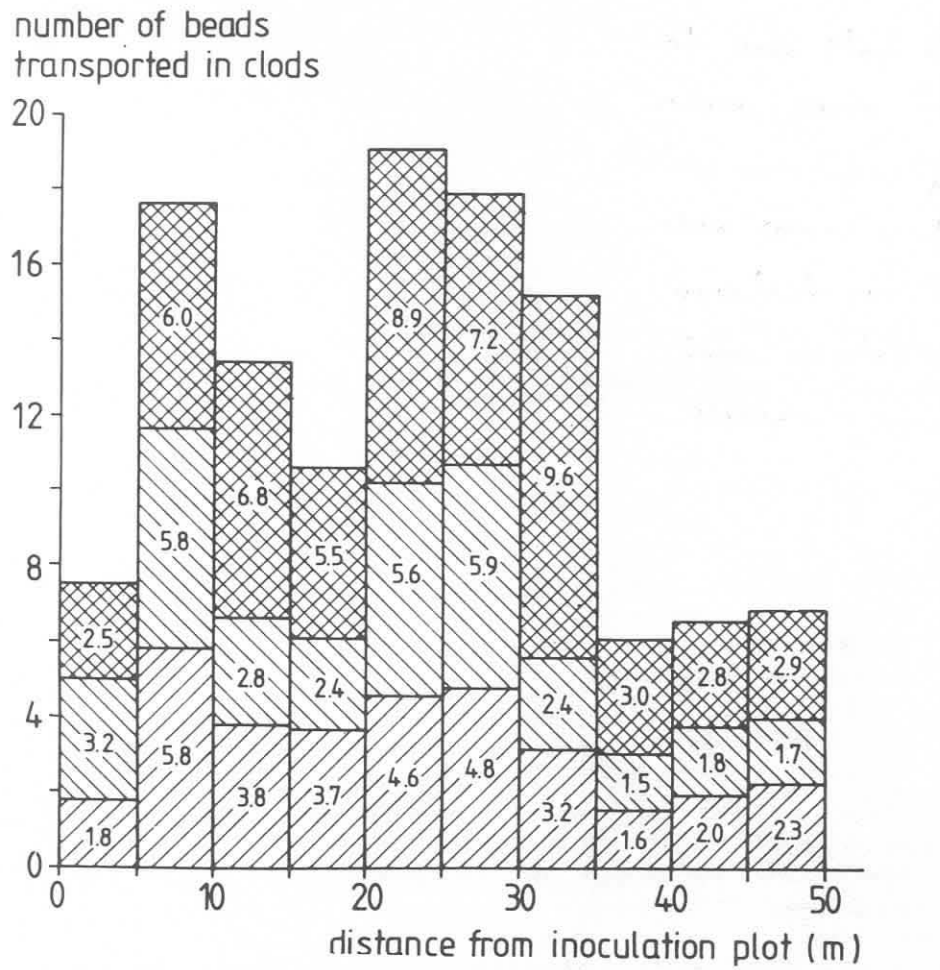

Fig. 2. Number of beads in clods transported by the tractor wheel, in relation to distance from the inoculation plot. Mean of 5 replicates.
▨ = Yellow beads (1.5 cm depth)
▧ = Blue beads (3 cm depth)
▨ = Red beads (4.5 cm depth)

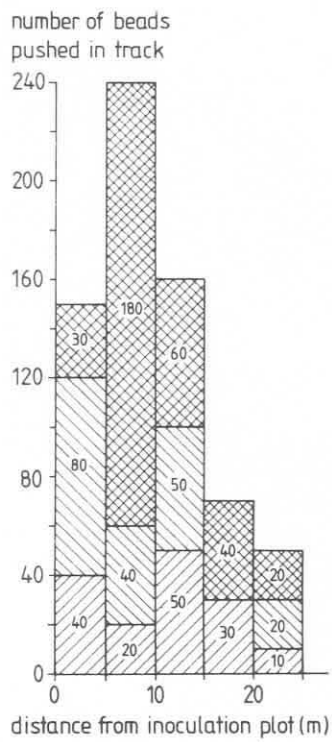

Fig. 3. Number of beads found in the track of the tractor wheels, in relation to distance from the inoculation plot. Hatching as in fig. 2.

Table 2. Total balance of beads inoculated and transported (Mean of five replicates)

	Yellow (1.5 cm)	Blue (3 cm)	Red (4.5 cm)	Total
Inoculated	960	960	960	2880
Left over after passage of wheel	415	527.5	492.5	1435
Transported in clods over 50 m	55.2	33.1	33.6	121.9
Pushed in track over 25 m	330	190	150	670
Over in soil adhered to tractor wheel	37.2	28	24.8	90
Estimated in track 25-65 m	56.2	52.5	53.4	162.1
Not accounted for	85.4	128.9	205.7	420

DISCUSSION AND CONCLUSIONS

In 1959, earthworms were present in the meadow near the farm (van Rhee, unpubl. results), and rare in at least parts of block-A (pers. comm. Doeksen, 1988). Nowadays, earthworms

can be found in the most southern parts of block A (see Fig. 1). They are scarce in the northern part of this block, which may be attributed to the present conventional treatment, in which nematicides have been used. Block B can be expected to have been uniformly unfit for earthworms, having received only inorganic fertilizer for 30 years. Under the new integrated management in part of block B it can be expected that conditions for earthworm survival have became much better. The presence of *L. rubellus* and in autumn 1987 also of *A. caliginosa* (unpublished results) points to this. The absence of earthworms in the minimum tillage plot is not as could be expected from data from other tillage experiments (Westmaas research group, 1984; Ehlers, 1975). The inoculum-experiment showed that *A. caliginosa* was able to survive and reproduce well in the minimum tillage plot during the summer 1987.

It seems likely that a colonization has taken place which proceeded from the farm yard over the grassland plots, and from thereon southward over the organically treated block A. During the survey for this research, the colonization border seemed to have just reached the minimum tillage plot.

From the field distribution the overall colonization rate would be approximately 175 m in 35 years, this is 5 m per year. This rate is lower than that found in grassland by Hoogerkamp *et al.* (1983). Here colonization proceeded with a rate of approximately 8 a year for *A. caliginosa* and *L. rubellus*. Grassland without worms was characterized by a 2.5-4 cm thick organic layer, which provided ample food to the pioneer population. Because the organic layer disappears in the centre of the earthworm plot, highest population growth can be expected at the population border, causing the relatively high rate of dispersal, assuming that the individual activity pattern is not changed under those conditions. Curry and Boyle (1987) studied the establishment of earthworm populations in reclaimed cut-over peat. They found a dispersal from inoculum sods of at least 2.5 m. yr^{-1} for *A. caliginosa*, and 10 m. yr^{-1} for *L. rubellus*, also under relatively favourable grassland conditions. The value found for the overall dispersion in this study is rather high compared to these values.

In the inoculation experiment, a rate of only 2 m was found for active dispersal of *A. caliginosa* for the main part of its activity period. It is therefore likely that in the colonization of block A also passive dispersal has been important. During wet years, earthworms of the species *L. rubellus* and *A. caliginosa* tend to remain at shallow depths, and also lay cocoons in this layer (unpublished results). Also in wet years, transport of soil by tractor wheels can be considerable. During harvest after the wet summer of 1987, tractor wheels carried a steady load of over 30 kg of soil after driving over a field in block A, which was found to contain 260 cocoons and 45 live earthworms, including some adults. On the other hand, farmers try to restrict tillage operations to dry periods, during which the amount of soil transported with the wheel is low.

The survival of cocoons transported by the wheel depends on several factors. The direct damage during uptake by the wheel is probably rather small, only five damaged cocoons could be found in the soil from the wheel at harvest 1987. Cocoons pushed into the track, which could represent half of the cocoons transported according to the passive dispersal experiment, can be expected to be severely damaged by the pressure. Those transported in the clods are dispersed over the soil surface and are in summer at risk under dry conditions, and in winter during frost. But if the cocoons are transported during harvest, often the soil is ploughed soon afterwards, increasing the chance that the cocoons are brought to safer depths before drying out is liable to occur.

Most of the cocoons on the tractor wheels will be transported over relatively small distances (15-25 m), as could be concluded from the dispersal experiment with the glass beads. However, small numbers of glass beads were spread with the clods that fall from the wheels at much greater distances, and can be expected to be spread even further than 65 m. So, in those years where cultivation is done under wet conditions, especially in the autumn, pioneer colonies may be started further from the colonization border than can be expected from natural dispersion. Within the field, the direction of tillage operations is SW-NE and vice versa, influencing the colonization of the block B from the block A very much. This is reflected by the relatively quick colonization of *L. rubellus* into the block B. In the North-South direction passive dispersal is not a regular process, but one that is unpredictable to a certain level, as the order in which the farmer works the fields is different throughout the year and from year to year.

Future plans are to fit the data from this study, and literature data for other species into the model of dispersal that has been described by van den Bosch *et al.* (in press).

SUMMARY

Colonization of an arable field by earthworms was studied in a newly reclaimed Dutch polder. The rates of spread of recently introduced populations and populations established 30 years ago, both on an experimental farm near Marknesse in the ''Noord Oost Polder'' are shown. Factors influencing colonization of arable fields, related to population dynamics and passive dispersal, are discussed. From the results, it appeared that in arable soil active dispersal is slower than in grassland situations, while dispersal by mud transport on tractor wheels can be considerable.

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